TRIZ-based Networks of Evolutionary Trends supporting R&D Strategy Definition

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Abstract: Improving the efficiency of R&D strategy definition is more and more crucial both for private and public organizations in order to combine the capability to propose innovative products and services with the reduction of lead time and expenses. In this context a crucial issue is the capability to identify the evolutionary scenarios for a given Technical System having a concrete chance to appear and the availability of means to assess the maturity of the related technologies involved. In this context, the authors are working on the development of systematic procedures to build robust technological forecasts and means to support strategic R&D choices through evolutionary maps and maturity assessment means. The research relies on the TRIZ Laws of Engineering Systems Evolution to build a Network of Evolutionary Trends (NET) for the Technical System under study, and on the analysis of the type of contradictions characterizing each branch of the NET as a means to assess the relative technological maturity of the corresponding scenarios.

Key words: TRIZ, Technology Forecasting, Maturity Assessment, Laws of Evolution, Contradictions.

1- Introduction

Nowadays the analysis of emerging technologies and their potential impact on markets, economies and societies requires reliable and repeatable methods and tools since the related information plays a critical role for strategic decisions of private and public organizations. Therefore, it is not surprising that more than fifty methodologies with different characteristics and specific purposes have been proposed so far in this field [P1]. Nevertheless all these techniques reveal several weaknesses [KD1] as: limited accuracy on middle and long-term forecast; poor repeatability; poor adaptability, i.e. no universal methods are known, besides complementary instruments must be integrated according to the specific goal and data availability.

Within this context TRIZ is emerging as a systematic forecasting methodology and the TRIZ community widely claims the benefits arising from the application of Altshuller's Laws of Engineering System Evolution (LESE) [A1, S1] and the corollary trends identified so far. Besides, as already discussed in [KD1, K1], also TRIZ instruments suffer from limited repeatability (different teams work independently produce different scenarios) and lack of accredited procedures for their application.

In facts, several TRIZ tools have been proposed to support technology forecasting activities: S-curve, system operator, laws of technical systems evolution, lines of evolution (trends), Ideality increase, morphological analysis, wave model of systems evolution, ARIZ (the Algorithm for Inventive Problem Solving) [A1, A2, A3]. Nevertheless, while these tools reveal relevant potentialities in several specific situations, their integrated use is limited to inventive problem solving tasks (ARIZ), while it is still missing for forecasting applications.

The present paper summarizes the authors' approach to analyze a Technical System (TS) and to model and to assess its evolutionary potential. After positioning the present research with respect to the relevant related art, section 3 describes the original step-by-step algorithm developed for analyzing the evolutionary potential of a TS. The main function of the TS, together with its working principle, is modelled as detailed in [CR1] and the model is then compared with previous generations of the system in order to build a structured classification of the information, suitable for evolutionary comparisons.

These comparisons allow to build a network of scenarios with different involvement of resources, which constitutes a map of the TS evolution, where already commercialized products are visualized together with emerging patented inventions and free spaces for investments. Section 4 details the original approach to identify the contradictions characterizing the evolution of the technologies to be compared and the related correlation analysis. In section 5, these criteria are applied to the past and current technologies adopted in the pharmaceutical manufacturing sector for tablets production. The case study allows to discuss about the potentiality to adopt the proposed correlation analysis as a means for maturity assessment.

2- Related art

2.1 – TRIZ instruments and forecasting

Fey and Rivin in [FR1] first positioned TRIZ as a "powerful structured methodology for a directed development of new products/processes" alternative to more classical Technology Forecasting approaches like trend extrapolation, morphological analyses and Delphi methods. Besides, the methodological description was limited to the LESE with a number of examples, without providing proper details about the way the TRIZ laws should be applied. Then Cavallucci in [C1] started integrating TRIZ LESE into the product development cycle as a means to predict the impact of a technical solution. The abovementioned approaches, indeed adopted by several TRIZ professionals and implemented in some software applications, are helpful to explore variants of the analyzed TS, but no directions are provided to identify elements and functions to be evaluated and further developed according to the LESE.

In facts, even authors like Mann [M1], who claim the incorporation of TRIZ trends of evolution into a "design method that allows individuals and businesses to first establish the relative maturity of their current systems, and then, more importantly, to identify areas where evolutionary potential exists", limit their attention to list of examples without any instruction about the object of the comparison according to the proposed evolutionary metrics.

As a result, the repeatability of the process is poor and strongly dependent on the skill and the experience of the analyst. It must be mentioned that a few TRIZ professionals have proposed integrated procedures for technology forecasting purposes [S2, ZZ1]; nevertheless, the authors believe that both Directed Evolution by Zlotin, Zusman and Evolution Trees by Shpakovsky are still mostly focused on the interpretation of the LESE, than on the analysis of the system the forecast is about. Such a lack of preliminary classification, especially in case of complex systems, is the main reason for poor repeatability of TRIZ forecasts, since different researchers apply TRIZ LESE to different details/characteristics of the same technical system and/or limit their study to superficial features of the system itself. In order to overcome these limitations, the authors have developed an algorithm for functional modelling, specifically tailored for TRIZ-based evolutionary analyses [GC1].

2.2 – Evolution of technical systems and related contradictions

According to the first two postulates of TRIZ, the evolution of Technical Systems follows objective laws and overcoming contradictions is the inherent mechanism which determines TS development. These postulates are clearly strictly related to each other; nevertheless, their coexistence is just "perceivable" into the classification of the Inventive Standards, while it is almost hidden in ARIZ, as well as in other items of the TRIZ Body of Knowledge. As a matter of facts, in classical TRIZ there are no formalized tools to correlate the evolution of a TS with its contradictions: in [A1] Altshuller, through the well known curves of system development, number of inventions, profitability, level of inventiveness (figure1), implicitly highlighted the conceptual link existing between the maturity of a TS and its contradictions, since the latter index is measured through the degree of contradiction resolution. Besides, these curves are hardly usable for practical scopes, despite what has been claimed in several publications like [GC1, GS1, M2], also due to the lack of information about the way Altshuller himself built them (therefore, with no references about their limits of validity).

In facts, in these papers the technology maturity curves are usually fuzzily rebuilt, often with relevant details missing (e.g. x and y values in [M2]), and with extremely doubtful determination of the inventiveness level [GC1, GS1].

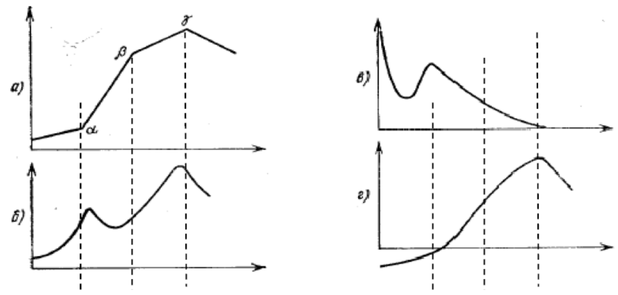

Fig. 1: Correlation between the stages of the "life" S-curve of a technical system (top, left) with the number of inventions (bottom, left), the level of inventiveness (top, right) and the related benefit, i.e., profitability (bottom, right) [AS1].

Indeed, numerous attempts have been accomplished to systematize the count of inventions, but just time consuming manual analyses allow to filter out not relevant patents selected through standard computer search criteria. The determination of the Level of Inventiveness evolution is even more difficult, since it is supposed to be done through a careful identification of the contradictions behind the problem solved by the patented inventions and, most of all, by the assessment of the degree of elimination of the contradictions themselves, which is extremely time consuming. Besides, no practical means still exist to speed up the identification and assessment of the contradictions approached by a patented invention, despite preliminary studies have been published in [CR2].

According to these issues, it emerges the necessity to find out further correlations between the maturity stage of a technology in a certain field of application and other technical information, possibly manageable with computer means to improve the efficiency of the process. Out of TRIZ literature, Technology Assessment (TA) has greatly evolved since the early experiences of the 1960s [W1], but still there isn't a single, widely disseminated and applied methodology. Many different approaches to TA have been adopted in practice, depending on the specific aims and scope of the application and its context (institutional, private firms, private or public research centres, specific industries etc.) [AM1].

Due to the lack of an established TA approach, neither in the scientific literature, nor in the industrial practice, the authors have decided to investigate the possibility to correlate the maturity of a technology with the evolution of the contradictions underlying its application in a certain field. The existence of such a correlation is expected according to the fifth law of evolution (uneven development of TS parts) and addressed also by Cavallucci and Rousselot [CR3], where the purpose is indeed different: ordering the contradictions in accordance to the fact that they present an opposition to a specific law.

The authors have focused the search for correlations between the evolution of TS contradictions and the LESE on the law of Ideality increase, due to some evidences arising from classical TRIZ literature. In facts, the growth of the degree of ideality can be compared with the consumption of resources according to the wave model by Salamatov [S1], as depicted in fig. 2. By combining the S-curve of TS performance with such a bell shape resources consumption three main stages of evolution can be recognized.

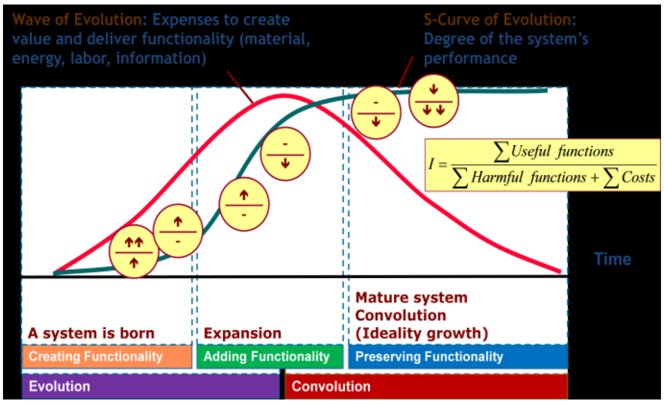

Fig. 2: Trend of Ideality increase (~~red~~ green line) compared with the consumption of resources (~~green~~ red line) which reflects the wave model by Salamatov [S1].

The specific objective of the present paper is to describe the original integrated procedure developed by the authors to build the NET by applying the TRIZ laws of evolution and to assess the maturity of each evolutionary branch through a correlation analysis applied to the nature of the related contradictions.

3- Algorithm for building a Network Of Evolutionary Trends (NET)

As stated in the previous section, the crucial issues are the identification of the proper function(s) delivered by the analyzed system, the influence on its evolution of auxiliary functions and undesired side effects, the competing alternative technologies. In order to provide systematic directions to functions' classification and to adopt a terminology well known by the scientific community, the algorithm is based on well established models of Design Theory.

3.1 Integrated model for function-behaviour analysis

The expected function of the TS under study is represented as a black box channelling or converting energy (E), material (M) and or signals (S) flows according to the classical EMS modelling approach [PB1]. In order to reduce ambiguity at the modelling level and to improve repeatability of the models, flows and actions are defined as indicated by the NIST functional basis [HS1], thus splitting the system into elementary functions. As already formalized by Gero since the first publication of the FBS framework [GR1], systems sharing the same motivation for existence (i.e. the same Function), can be characterized by different Behaviours provided by their different Structures (i.e. entities, attributes of these entities and relations among them). It is of paramount importance for performing evolutionary comparisons between competing technologies, to identify behavioural and structural differences with explicit models. As detailed in [CR1], the authors suggest to model the Behaviour of a TS still keeping a close relationship with the EMS representation of function, by adopting the TRIZ model of a minimal technical system [A1]. According to the first Law of Engineering Systems Evolution, i.e. the Law of Completeness, a system capable to deliver any function must be characterized by four elements (fig. 3, above):

- a Tool, which is the working element delivering the function of the TS, i.e. exerting a certain effect on its object;
- an Engine, i.e. the element providing the energy necessary to produce the expected effect of the function;
- a Transmission, i.e. the element transmitting energy from the Supply to the Tool;
- a Control, i.e. an element governing at least one of the above elements.

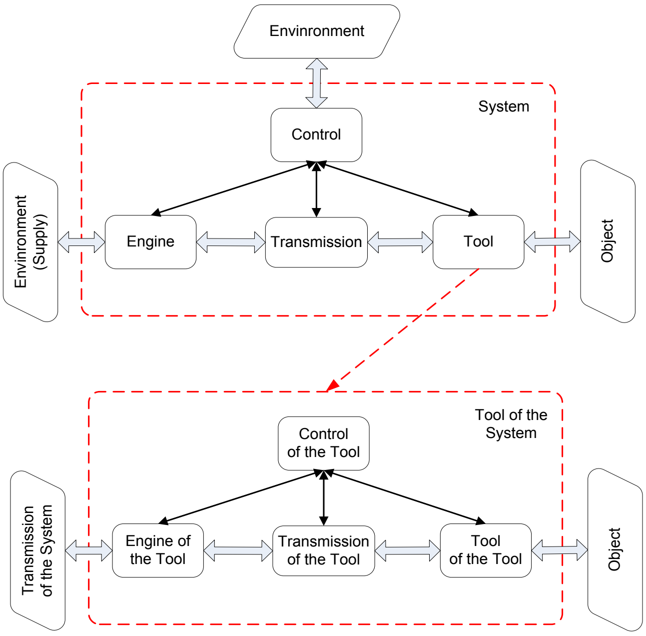

Fig. 3: Minimal Technical System (above) and hierarchical decomposition of its elements (below).

The classical TRIZ definition of the minimal technical system considers just energy flows and typically the Engine is identified going back from the Tool upward the energy flow, until a transformation in the type of energy is found (e.g. from electrical to thermal due to the Joule effect). Besides, according to the authors' experience, the concept of the Law of Completeness of System Parts can be extended also to different types of flows, namely Material and Signals, as clarified in section 3.2. Among the others, the adoption of a four blocks decomposition of a TS provides at least the following benefits: it keeps a manageable number of elements to be contemporarily taken into account; it invites the analyst to focus the attention just on the elements relevant to a specific function at a time. Nevertheless, the model can be deepened to the necessary detail level by further decomposing each of the four elements as depicted in fig. 3 below, by following the directions of the System Operator, another key item of the TRIZ body of knowledge, constituting at the same time an effective tool for avoiding psychological inertia in problem solving process, as well as the essence of the way of reasoning of a creative person [AV1].

Figg. 4-6 clarify the structure of the integrated model by means of an example from the pharmaceutical tablets manufacturing sector: the production of tablets consists in combining active principle, excipients and possibly further additives in order to form the tablets through a compression of granules (typical processes) or a direct compression of fine particles (recent developments due to the adoption of a novel type of excipients). The system is modelled through EMS boxes and decomposed into elementary functions until each functional unit can be described in terms of flows and actions belonging to the reference list proposed in [HS1] (fig. 5). It is worth to notice that the functional models report only the necessary flows (e.g. the particles and the solvent to be mixed), while auxiliary flows, which depend on the specific design choices performed to deliver the expected function, are omitted: besides, they appear in the Behaviour models.

Then the Behaviour of each elementary function is represented by means of the TRIZ minimal model of a technical system. Fig. 6 shows the outcome of this step for Solution and Drying, i.e. the first two elementary functions of the diagram in figure 4.

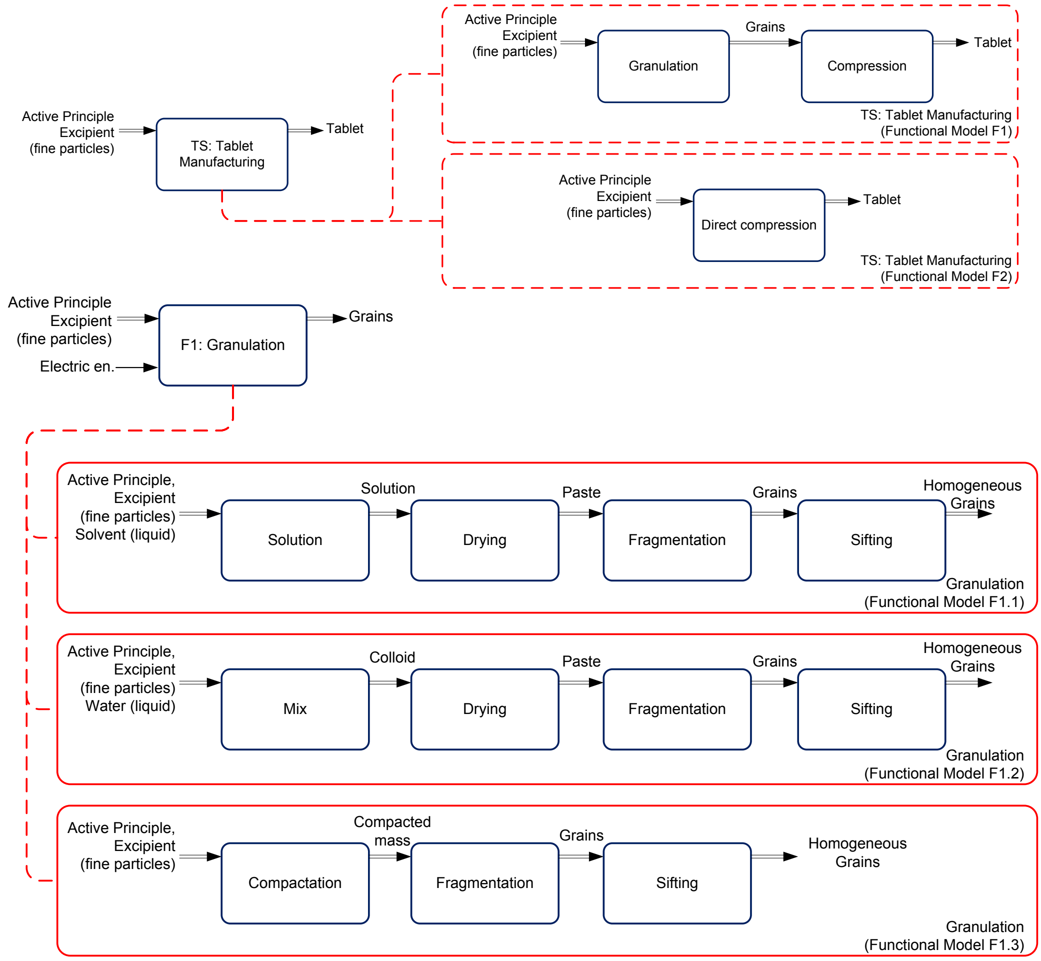

Fig. 4: Functional model of a pharmaceutical tablet manufacturing process. EMS model of the overall TS and preliminary identification of the alternative technologies (above). Detailed functional decomposition of the granulation phase (below).

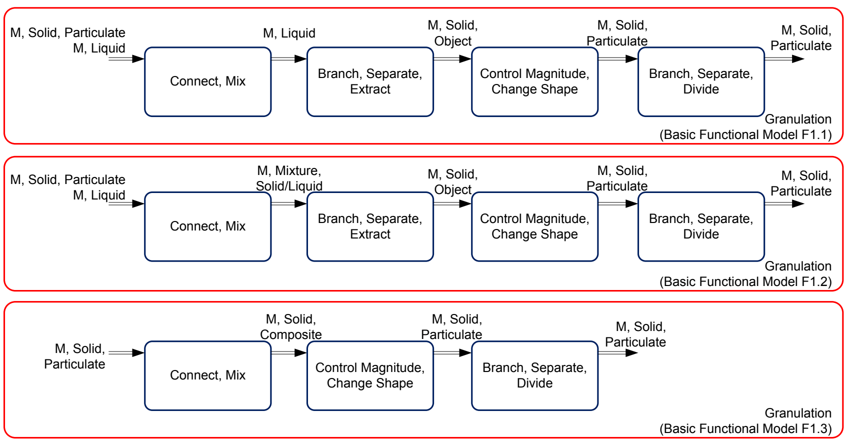

Fig. 6: Elementary functions of the granulation phase according to the functional basis [HS1].

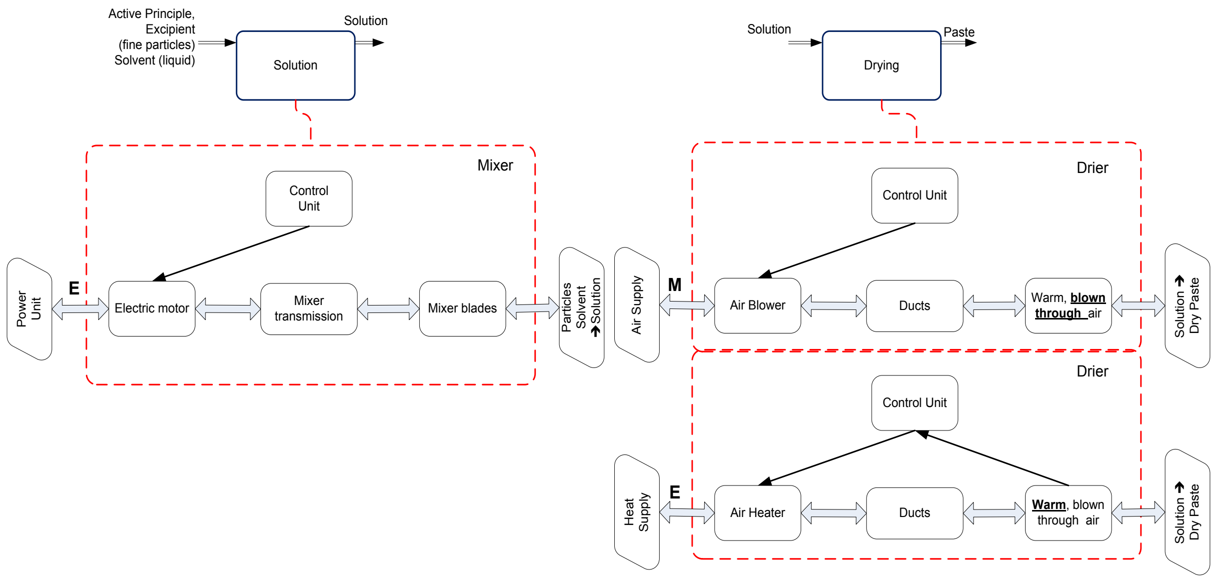

Fig. 7: Exemplary Behaviours of the first two elementary functions of figure 4 represented through the TRIZ minimal model of a technical system.

In fig. 7 left (Solution) the product is constituted by particles and solvent which are transformed into a solution; the element directly acting on particles and solvent is the blade of the mixer, thanks to its motion which increases the kinetics of the chemical reaction. The rotation of the mixer blade is introduced by an electric motor which constitutes the engine of the model; the transmission is represented by the blade shaft while the supply (Energy flow) is a power unit connected to the electric motor. Finally the control acts by regulating the rotational speed of the motor itself. In fig. 7 right (Drying) the product is the paste derived by the solvent removal from the input solution; a typical Behaviour of a drier is constituted by a worm air flow blown through the solution until the required residual moisture content is reached; thus the air is the tool capable to dry the solution thanks to two complementary properties: high temperature and motion through the product. In this case, two minimal models must be built, each describing how those properties are provided. In facts, an air blower is the engine to move the air through the solution, while an air heater is the engine to have warm air. The other elements are identified consequently. The presence of a temperature feedback is represented by means of an arrow from the warm air to the control unit.

Once that the available Behaviours have been modelled for each elementary function, a Su-Field model related to the interaction of each pair of interacting elements of the Minimal Technical System model is added (i.e. Tool-Product, Transmission-Tool etc.). Fig. 8 reports two exemplary Su-Field models related to the Tool-Product interactions of Fig. 7. It is worth to notice, that thanks to the classical TRIZ classification in terms of useful/harmful, sufficient/insufficient interactions, these Su-Field models allow to represent also the actual Behaviour of a TS, and not just the expected one which derives from the functional model; in other terms, the proposed approach allows to represent into a unified model the comparison between the desired behaviour (Be) and the behaviour extracted from the structure (Bs) [GR1]. Moreover, the Su-Field model highlights the nature of the interaction, which is relevant for evolutionary analyses according to the TRIZ Standard Solutions (mostly Class 2 and 3) [A1].

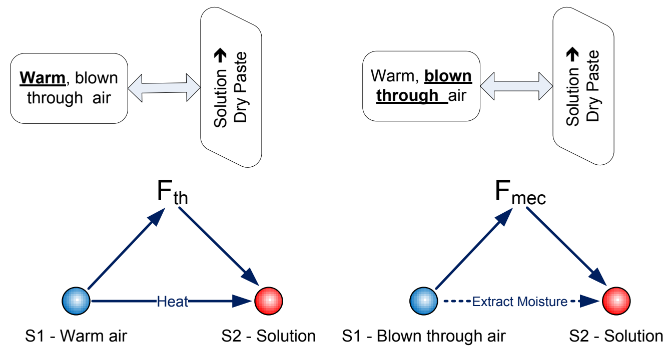

Fig. 8: Exemplary Su-Field interactions between pairs of elements of the minimal models of technical system representing the Behaviours of the TS functional units.

3.2 Step-by-step NET Algorithm

The main steps of the proposed algorithm are represented in figure 9, together with the main sources of information. The preliminary analysis of the TS aims at the identification of the main Function, the Structure and the Behaviour of the system at different detail levels, both of its current version and its historical evolutionary steps. Then the resulting functional and behavioural models are compared according to TRIZ Laws of Engineering Systems Evolution (LESE). The third step consists of assembling the relevant trend recognized for each element into a map representing also: links between different generations of the TS characterized by a different behaviour, usually due to a Transition to Micro-level; links between the four elements of each minimal technical system associated to each function and links between an element and its subsystems. Browsing the NET is then possible to identify missing implementations of the TS through trends interpolation/extrapolation: within this fourth step, unexpected patent activities of the competitors are likely to appear, as well as virgin scenarios where to focus R&D activities. Finally the limits of the NET validity must be checked by analyzing what happens if an assumption fails or a certain functional parameter has sudden variations out of the expected range.

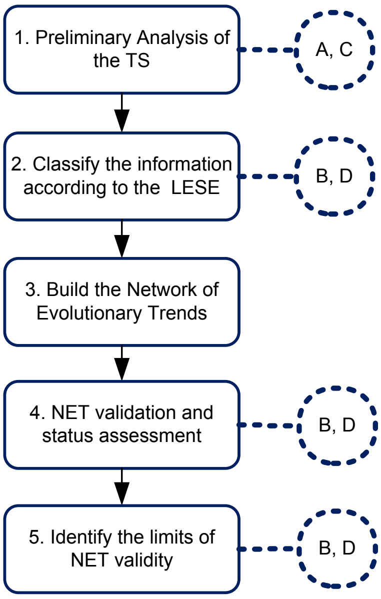

Fig. 9: Main steps of the algorithm and relationships with Information sources and gathering tools: A = experts through structured questionnaires; B = experts by LESE; C = patent literature through structured questionnaires; D = patent literature by LESE.

Each of the abovementioned steps consists in several sub-steps and clearly requires a detailed description within the limits of the paper extension.

1. Preliminary analysis of the TS

1.1 Identify the Main Useful Function (MUF) of the TS, its characterizing parameters and expected values

- Identify the Evaluation Parameters defining the performance of the MUF
- Decompose the MUF, according to the Functional Basis [HS1], into elementary functions needed to impact those Evaluation Parameters (e.g. fig. 6)
- Identify constraints and minimum performance values (e.g. due to standards, certification systems etc.)

1.2 Analyze the goal of the TS and the role of its MUF at a super-system level; identify all the functions acting on the same object of the MUF

1.3 Identify the alternative Behavioural Models (BM) of the TS capable to produce the expected MUF

- This task should be performed taking into account also out-of-date configurations of the TS
- Only different BM of the MUF should be mapped, while other differences between possible embodiments (structures) of the TS can be neglected at this stage

1.4 Identify the Auxiliary Functions requested by each specific BM of the MUF

1.5 Identify the undesired Harmful Effects generated by each specific BM of the MUF

- This step leads to the identification of Technical Contradictions in the following form: the Structure of the TS should have the behaviour represented by BM in order to deliver the MUF, but should not have such a behaviour in order to avoid its harmful effects

1.6 Identify the amount of resources required by each BM to deliver the MUF

- In order to allow a comparison between different systems with the same BM, the resources should be normalized to the same performance parameter or vice versa performances can be compared with respect to the same usage of resources
- In order to allow a comparison between different BMs, resources should be grouped into homogeneous classes, the most general classification being resources related to Space, Time, Energy, Material, Information
- The analysis of the resources must take into account also the Auxiliary (necessary) Functions identified at step 1.4

1.7 Build the Minimal Technical System model of each BM of the MUF and of the other functions identified at step 1.2-1.4 (e.g. fig. 7)

- Complete the model with Su-Field analysis of each pair of interacting elements (e.g. fig. 8)

2. Classify the information according to the LESE

2.1 Compare the BMs of the MUF according to the Law of Transition to Micro-level

- The transition from macro to micro level, i.e. a transition to a smaller scale of the principle a BM is based on, is a typical trend of technical systems. Since such a transition is typically associated to major changes in the TS, it is suggested to apply this classification of the BMs before proceeding with more detailed comparisons

2.2 Analyze the Structure associated to each BM of the MUF and its level of completeness according to the first Law of evolution

- Check if the supply of the flow characterizing the MUF is integrated in the TS
- Check if the control of the flow characterizing the MUF is integrated in the TS and which is the controlled element
- This step, as well as the following, should be performed iteratively for each BM of the MUF

2.3 Analyze the Structure associated to each Auxiliary Function and its level of completeness according to the first Law of Evolution

2.4 Analyze the interactions between each pair of elements of the Minimal Technical System for each BM of the MUF and perform a comparison according to the LESE and the TRIZ trends of evolution [A1, S1]

- The priority should be given to the interaction existing between the Tool and the Object, then to the other pairs of elements, i.e. Transmission-Tool, Supply-Transmission, Control-Tool etc.
- Among the different formulations of TRIZ trends of evolution available in literature, the authors make use of the following to be applied to each pair of elements
- Increase of controllability: introduce closed-loop feedbacks, move the control closer to the tool
- Geometric harmonization: geometrical evolution (1D-2D-3D and related modifications), increase of asymmetry, segmentations (voids, surface, volume), dynamization
- Rhythm harmonization: parts coordination, frequency of action
- Material harmonization (it is worth to note that this is not a classical TRIZ trend; nevertheless, the authors have encountered several systems evolving towards a harmonization of the materials of interacting elements)
- Mono-Bi-Poly and Trimming: Mono-Function Homogeneous systems, Mono-Function systems with

Shifted Characteristics, Multi-Function Heterogeneous systems, Inverse Function, Partial Trimming, Extended Trimming; the assessment of the evolution-convolution stage should be performed also by taking into account the ratio between the performance of the function under analysis and the resources involved for its implementation

- Increase of Fields involvement

2.5 Analysis of the contradictions and their relationships with the trends formulated at step 2.4

- Contradictions identified at step 1.5 disappearing due to the application of one or more trends
- Contradictions identified at step 1.5 not solved by the trends
- New contradictions emerging by the application of a specific trend of evolution
- New contradictions emerging by the application of two or more trends generating conflicts between the available resources

3. Build the Network of Evolutionary Trends

3.1 Order the Minimal Technical System models of each BM of the MUF according to the trend Transition to Micro-level analyzed at step 2.1

3.2 Within the same stage of Transition to Micro-level, order the BMs according to their completeness (without recurring to the support of external systems or to humans)

3.3 Add the models of decomposed subsystems (figure 3)

3.4 Add the models of the functions identified at step 1.2

3.5 Represent as branches of a network the trends identified at step 2 by links to the corresponding elements of the model built at steps 3.1-3.4

4. NET Validation and status assessment

4.1 Mark the nodes of the network corresponding to an existing configuration of the TS

- The authors usually apply a red circle around these nodes; further differentiations can be applied by highlighting with different colours sub-classifications like competitors, years of development, market sectors etc.

4.2 Mark the nodes of the network corresponding to features found in patents, but still not brought to the market

- The authors usually apply a yellow circle around these nodes (figure 10, above).

4.3 Identify new opportunities of implementation of the TS

- Recognize interpolation opportunities due to missing configurations in a trend of evolution (figure 10, middle).
- Recognize extrapolation opportunities due to not exhausted trends of evolution (figure 10, below).
- These opportunities are marked with a green circle.

5. Identify the limits of NET validity

5.1 Search for functions alternative to the MUF capable to achieve the same overall goal

- It is suggested to start from the results of the analysis performed at step 1.2 and to apply the System Operator in order to identify alternative functions providing the same benefits of the MUF to the Super-System

5.2 Analyze the parameters of the object of the MUF and check which variation of such parameters makes the TS incapable to provide the expected benefits, thus failing in the achievement of the goal

5.3 Analyze the parameters of the object of the MUF and check which variation of such parameters makes the TS useless

5.4 Investigate the impact of the removal of the constraints identified at step 1.1 or the introduction of new ones

The description of the algorithm (and most of all, steps 2.4 and 2.5) should be further detailed, but due to space limitations the authors have limited the explanation of tasks accomplished according to procedures already well discussed in literature (e.g. [S2, ZZ1]).

It is worth to notice that the structured approach of the investigation together with the precise directions of search provided by the trends (e.g. in step 2.4) allows to perform very precise questions to the experts, thus triggering their implicit knowledge, as well as to make use to a maximum extent of the functionalities provided by modern Text-Mining technologies, while analyzing electronic documents like patents and scientific papers.

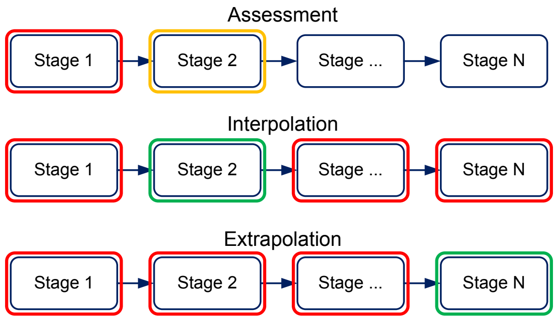

Fig. 10: Evolutionary assessment of the NET branches and identification of new opportunities for the TS.

4- Correlations between the evolution of contradictions and the maturity of a technology

In order to explain the proposed approach to study the existence of correlations between the evolution of the contradictions characterizing a certain TS and its stages of development, it is worth to recall the model of a TRIZ contradiction. The authors have adopted the OTSM formulation [KD2], which distinguishes between Evaluation and Control Parameters (fig. 11).

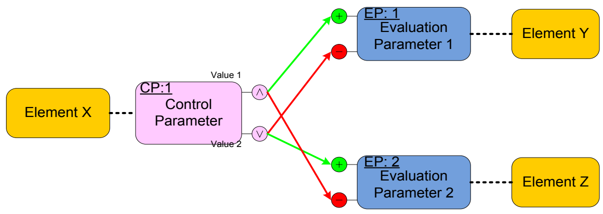

Fig. 11: OTSM-TRIZ model of contradiction [KD2].

Aiming at the highest repeatability of the analysis, the authors have developed a set of well defined rules to identify and classify the Evaluation Parameters (EP) of each Function/Behaviour; similarly, the Control Parameters (CP) of each Behavioural Model (BM) are clustered on the base of general rules. Eventually, it is necessary to check the relationships between CPs and EPs in order to identify the contradictions characterizing each BM. A detailed description of the CP/EP identification and clustering criteria has been published on [BC1].

The basic principle is to distinguish between three main classes of EPs: Performance of the Main Useful Function and of other Useful Functions delivered by the TS; Harmful

Functions; Resources consumption. By definition, the former parameters are just related to the function accomplished by the TS and not to its Behaviour and Structure, i.e. the way the function is delivered. Besides, other EPs represent a measure of the undesired side effects (harmful functions) and the consumption of resources to make the system work. It is clear that the latter two categories of EPs strongly depend on the nature of the Behavioural Model and the Structure of the TS.
In order to analyze the evolution of a given TS and to assess the maturity stage of the available technologies, it is possible to compare the nature of the EPs involved in the contradictions characterizing each BM of the NET under study, i.e. representing alternative past and present technologies delivering the same function.
Indeed, different types of EPs are supposed to be involved in a different manner along the evolution from the infancy stage to the maturity. For example, according to the wave model by Salamatov [S1] shown in fig. 2, the consumption of resources changes with a definite regularity.
According to what has been published on [BC1], the percentage of contradictions between EPs related to system performance dramatically drops at the end of the emerging stage and keeps declining up to obsolescence. Besides, the percentage of contradictions between conflicting consumptions of resources regularly increases with system maturity. Thus, by comparing the relative percentage of these classes of contradictions it is possible to perform at least a rough estimation of the maturity level reached by a given technology.

5- Exemplary correlation analysis between evolution of contradictions and TS development

The authors have already experienced the NET modelling approach in six case studies related to disabled walkers, wood pellets production, aseptic filling of beverage containers, tablets production, household electric appliances and mufflers for combustion engines; in each of these case studies conducted from September 2007 to May 2010 the role of the authors was the definition of a structured set of scenarios to support company's management in the selection of the most appropriate directions for investment. The algorithm was carefully applied to collect and classify the implicit knowledge of company's experts, as well as to direct the search for further relevant information from patent databases and other scientific sources. In this section the proposed classification and correlation analysis is applied to the case study in the field of production of tablets in the pharmaceutical manufacturing sector, since several technologies have been developed in the last decades and it is possible to appreciate the substitution process of emerging techniques over mature ones.
The tablet production process consists in agglomerating the Active Principle Ingredients (API) from a powder status into pills. All the existing technologies make use of excipients to improve the manufacturability and the conservation properties of the drug. Two main classes of processes can be distinguished: the largest majority of current production plants make use of an intermediary granulation phase to ease the moldability of the raw materials (fig. 12). Recently, direct compression has been applied to some APIs. Figure 4 shows the EMS model of the whole process and the functional decompositions characterizing these two major techniques.

Due to the availability of detailed information from the industrial partner of the present study, a particular attention has been dedicated to the granulation phase. In the past, granulation was performed through the production of a solution to be homogenized, dried and eventually reduced to granules. After the introduction of severe limitations about solvents usage, wet granulation technologies have adopted water to substitute solutions with particle suspensions, but still keeping the same machinery. Recently, dry granulation processes have been proposed to reduce the harmful impact of water residuals into the tablets and to improve the efficiency of the overall production process. Therefore, the detailed analysis has been performed on the following technologies: High Speed Granulation (HSG), Fluid Bed Granulation (FBG), Spray Drying (SD), Dry Granulation (DG), Pneumatic Dry Granulation (PDG) (fig. 12).

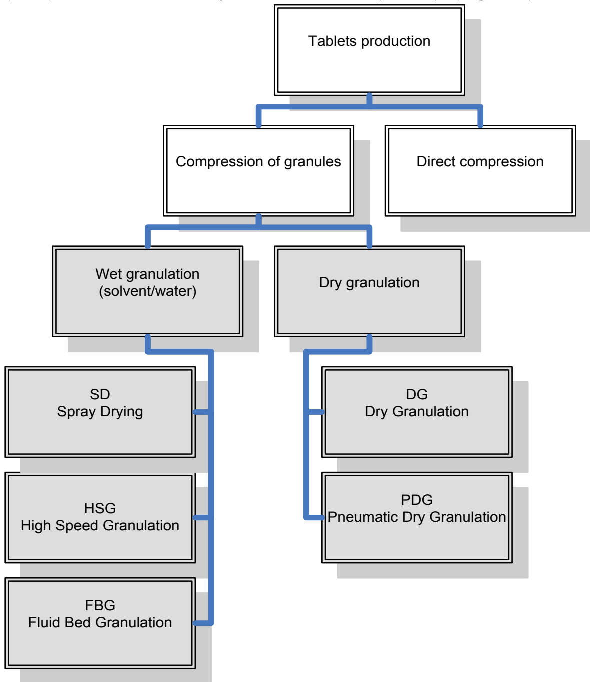

Fig. 12: General classification of tablets production technologies, based on the compression (white boxes) and the granulation (gray boxes) phases.

Each of the five granulation technologies has been decomposed into elementary functions according to the NIST classification, as described in section 3. Due to space limitations it is not possible to show all the functional and behavioural models built; however, it is worth to list the identified elementary functions, since they will constitute the main object of the evolutionary comparison between maturity level and contradictions types.
- HSG: Mixing (API, excipients, water), Fragmentation, Drying, Fragmentation, Sifting;
- FBG: Mixing (API, excipients), Fluidize, Agglomerate, Drying, Filtering;
- SD: Mixing (API, excipients, water), Atomizing, Drying, Sifting;
- DG: Mixing (API, excipients), Compacting, Pre-crushing, Flake Crushing, Sifting;
- PDG: Conveying (API, excipients), Compacting, Pre-crushing, Flake Crushing, Fraction.

Then, each of the elementary function has been analyzed in order to build its Behavioural Model through one or more

Minimal Technical System models, as depicted in figg. 7-8. As a result, 14 different BMs have been recognized:

- BA1: agglomeration of fluidized powders by means of a liquid binder in a closed bin (Fluid Bed Agglomeration);
- BC1: powders compressed into a ribbon by means of two opposite counter rotating rollers (Roller Compaction);
- BD1: pneumatic conveying of particles/powders;
- BM1: mechanical mixing of powders and binders by means of moving surfaces;
- BM2: pneumatic mixing of powders by fluidization (fluid bed mixing);
- BM3: mixing of powder by means of moving surfaces;
- BF1: mechanical fragmentation of wet mass by means of calibrated nets;
- BF2: mechanical fragmentation of dry compacts (slugs or flakes) by means of oscillating rollers: oscillating granulation;
- BF3: flakes spheronization;
- BS1: Vibro-sieving;
- BS2: PDG “smart” fractioning;
- BS3: cyclone separation;
- BE1= fluid bed drying;
- BE2= dehydration by means of a flow of warm air (oven).

Eventually, the EPs and CPs related to each BM have been identified: first, performance EPs are associated to each elementary function, according to the classification described in section 4. Then, the specific characteristics of each BM are analyzed to identify relevant resources and related harmful functions. Similarly, each minimal model of technical system allows to extract the CPs impacting the behaviour of the related technology. As a result, an elementary function characterizing different technologies (e.g. mixing, drying, sifting etc.) is evaluated through the same performance EPs, but possibly different resources and harmful functions EPs, depending on the specific way the function is performed (behaviour).
Fig. 13 shows an excerpt of the NET resulting from this analysis; due to confidentiality issues it is not possible to share all the conclusions which can be extracted from this study.
Nevertheless, some interesting comments can be shared in order to clarify the benefits of the proposed modelling approach.

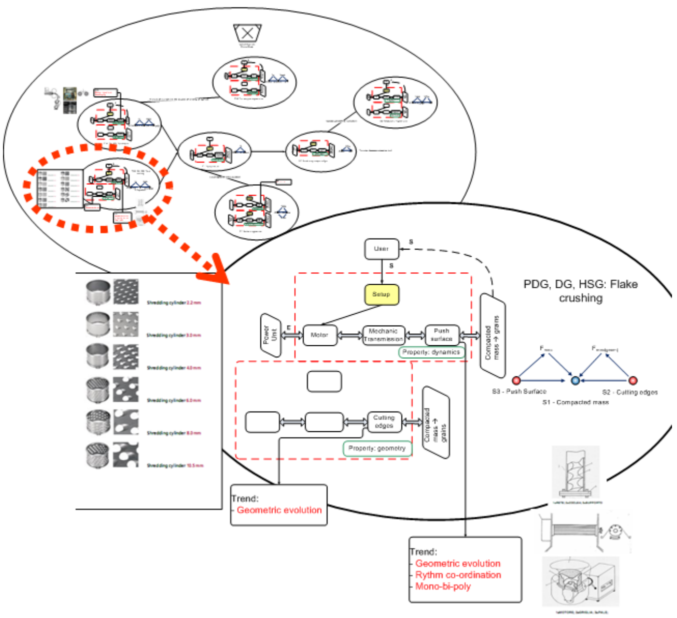

Fig. 13: Excerpt from the NET representing the evolution of granulation technologies in the field of tablet production.

First, after splitting each of the existing technologies into elementary functions, the maturity assessment applied to the specific BM shows that not always more recent technologies result more “evolved” of past technologies. In other terms, the adoption of new means to deliver a specific elementary function has often implied the need to recur to more obsolete techniques for the other elementary functions. For example, the PDG is certainly the most “advanced” according to the way the key elementary functions are performed, but definitely “old-style” for flake-crushing.
Therefore, one of the first conclusions which can be drawn is that in the field of tablet production, there’s still space for some improvements in the granulation phase, by hybridizing the most advanced BM adopted to execute each elementary function of the process.
Nevertheless, all the current technologies reveal to be at a quite mature stage of development. Thus, a more radical transition is expected, either to micro-level (i.e. involving physical effects at a smaller dimensional scale), or to Super-system (i.e. eliminating the need of granulation by itself).
The above mentioned notes constitute a brief example of the information provided to decision maker with the proposed approach. The NET, by integrating references to the relevant patents of the specific field of application according to the formalism summarized in fig. 10, and a maturity index calculated through the correlation analysis applied to system’s contradictions, has demonstrated to be a valuable means to support strategic decisions for R&D planning in this domain.

6- Conclusions

The integrated procedure and modelling techniques presented in this paper allows to build with systematic and repeatable steps a Network of Evolutionary Trends to be used for supporting multi-criteria decisions and to highlight opportunities of development. Compared with TRIZ-based forecasting approaches published in literature, the authors have focused their attention on the definition of a precise procedure to identify the elements and the features to be analyzed and benchmarked according to the TRIZ Laws of Evolution.The choice of the favourite strategic direction is still assigned to the beneficiaries of the forecast according to their attitude to the world, their mission and values, as already suggested by Altshuller [A1]. Nevertheless, the proposed procedure carefully limits the evolution space by means of a detailed resources analysis.
Such a network of trends proved to be an effective tool for exploratory analysis of potential evolutions of a TS in several extended industrial applications. In this paper, in order to illustrate and clarify the proposed algorithm some details from a study in the field of pharmaceutical tablet production have been presented. Such an activity has lead to the identification of some specific solutions the company was not aware of, which are actually under development by company’s competitors. Moreover new R&D opportunities have been highlighted. All these results are considered a positive validation of the proposed procedure.
The authors are further developing the proposed algorithm with the aim of taking into account the analysis of entire business processes, where the evolution of each technical

system involved in the process is impacted also by the development of the engineering systems adopted in the other phases; thus, the process itself as a whole is considered as an evolutionary engineering system. As a non-negligible side outcome of the research, an extension of the classical FBS model is emerging, where the comparisons between expected and actual behaviour of the TS are modelled by taking into account its different life stages in a more holistic scenario.

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